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GREEN ROOF PLUG GERMINATION AND GROWTH WITH DIFFERENT BASE MEDIA AND TREATMENTS

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by

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TITLE: GREEN ROOF PLUG GERMINATION AND GROWTH WITH DIFFERENT BASE MEDIA AND TREATMENTS

CO-MAJOR PROFESSORS: Karen Stoelzle Midden and Dr. S. Alan Walters

The germination rates of four plant species (*Allium schoenoprasum* L., *Dianthus gratianopolitanus 'Grandiflorus'* Vill., *Sedum kamtschaticum* Fisch. & C.A. Mey. Spp. *ellacombianum* (Praeger) R.T. Clausen, and *Talinum calycinum* Engelm.) were compared with six fertility treatments (control, fertilizer - once a week, double fertilizer - twice a week, mycorrhizae, vermicompost, and green roof mix) that also evaluated a peat based greenhouse medium verses a lightweight aggregate medium integrated. The greenhouse medium had higher germination rates than the lightweight aggregate medium. The control, fertilizer, and double fertilizer, which were not applied until a month into the study, provided similar germination results.

The seedlings obtained from the germination study were grown into 3.81cm x 7.62cm plugs, with plant height, leaf count/width, and dry weight taken three months later. The greenhouse medium treatments control, fertilizer, and double fertilizer had the most leaves, and provided the tallest and widest leaves as well as the greatest biomass. The lightweight aggregate medium control displayed the lowest growth in this study. The fertility treatment that showed the most potential was the green roof mix. This mix significantly improved plant growth in the lightweight aggregate medium, which indicates the potential to improve greenhouse medium based plug establishment on extensive green roofs with aggregates.

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CHAPTER 1

LITERATURE REVIEW

Biodiversity has become an important consideration of green roof installations given the opportunity to support plant life in a built environment. Tallmay (2011) emphasizes the value of plants and how they support 'all the food webs on earth'. Worldwide, humans are using more and more land to cultivate crops, leaving other wildlife with less food and places for shelter. In urban areas, green roof habitats provide wildlife and plants the opportunity to live in an area that otherwise could not support plant growth, and is often considered wasted space. Additionally, many green roofs are closed to the public, providing an undisturbed environment for microorganisms, plants, insects, and birds to thrive (Getter and Rowe 2006). Jorgenson (2004) states that understanding the social and cultural content of urban planting is just as important as the technical design. Naturalized roofs are often referred to as "biodiversity roofs," and Dunnett (2006) describes four rules to increase biodiversity on green roofs: use only native plant species, locally-characteristic plant communities, local-provenance materials, and local soils and substrates. Many green roofs are now built utilizing these rules as guidelines. For example, in Basel, Switzerland, the policy for green roofs larger than 500 m^2 in area are required to utilize regional soils (Brenneisen 2003). The use of native plant materials and healthy establishment is also gaining interest for green roofs and is being widely evaluated by researchers. Monterruso et al. (2005) evaluated supplemental irrigation on a green roof to determine the survival rate of native perennial plants; and over the course of three years, the volume of irrigation water was decreased from supplemental irrigation during the first two years down to only rainfall as a water source by year three. In this study, only 4 out of 18 native perennial plants survived this decrease in water application. Oberndorfer (2007) indicates that extensive green roofs are harsh environments for native plants and they cannot survive long term without supplemental irrigation. However, with timely irrigation, a diverse number of plants can establish themselves and grow sufficiently to enhance biodiversity for urban planting (Monterusso 2005, Oberndorfer 2007). To improve biodiversity, native plants should be considered for green roofs instead of the typical *Sedum*. This switch to native flowers will support a greater number of insects and birds; although, supplemental irrigation may be needed to support them on a green roof (Dunnett 2006, Monterusso et al. 2005).

Green roof types. Green roofs have been in existence for centuries, some dating back as far as 500 BC. The styles of these roofs over the centuries have ranged from Norwegian sod houses to modern extensive and intensive green roofs (Getter and Rowe 2006, Magill 2011, Monterusso et al. 2005). The weight limit load of the roof dictates the type, whether extensive or intensive. Intensive roofs have a deep growing medium greater than 10 cm in depth and can have the ability to grow plants as large as trees (Alexander 2004). Extensive roofs are utilized more in cityscapes, typically have only 5 to 10 cm of a growing medium, and are most widely used due to their lighter load characteristics avoiding structural problems (Alexander 2004, Dunnett and Kingsbury 2008, Getter and Rowe 2006). Thus, most research is conducted on extensive roofs due to their environmental benefits as well as their ability to reduce noise pollution, improve aesthetics, increase biodiversity, and improve energy efficiency (Dunnett and Kingsbury 2008, Getter and Rowe 2006).

Leadership in Energy and Environmental Design (LEEDS) is an accreditation program in which the United States Green Building Council (USGBC) awards points to commercial buildings for participating in sustainable practices such as water efficiency and energy conservation. The construction and system of green roofs receive high ratings from LEEDS based on their functional aspects to manage storm water, improve polluted air, help reduce the "heat island effect," and especially those built using recycled materials (US Green Building Council 2011). Current green roof construction typically includes three layers: drainage, filter, and vegetation (Emilsson 2008). The drainage layer consists of a water proofing membrane, protection board, root barrier, and drainage course. The filter layer consists of filter fabric that supports the green roof medium and vegetation layer (Scholz-Barth 2001, Werthmann 2007). Many extensive green roofs are retro-fitted flat roofs having a limited load bearing capacity (Emilsson 2008). To reduce the load, an engineered low weight green roof medium is used versus soil and sand. In some cases, specialized golf course sand designed for good percolation is used in the mix. Most extensive green roofs use lightweight aggregate as a base; however, research is being conducted on the feasibility of other light weight media bases (Elstein et al. 2008, Emilsson 2008). Alexander (2004) and Boivin et al. (2001) state that besides being lightweight, a selected medium should provide sufficient root support, nutritional value, and minimize detrimental effects on the plants. Because lightweight aggregate is mineral in nature and does not decompose, organic materials such as compost must be added. The role of the compost is to hold moisture, balance pH, and add nutrients. According to Mather (2006), compost is desirable for its high nutrient content and microbial population, in addition to being a recycled material. However, there are challenges of excess compost, of main concern is the addition of excess weight to the roofs (DiNorsica and Buist 2009).

Another challenge of extensive green roofs is selecting plant materials that tolerate very harsh living conditions due to a shallow medium, high heat, and sparse water (Getter and Rowe 2007). Maintaining healthy plants may also incur additional maintenance costs. Getter and Rowe (2007) indicate that *Sedum* spp. are the most frequently used plants due to their drought tolerance and shallow root system. There are over 600 species of *Sedum*, but they are not the only plants that perform well on green roofs (Snodgrass and Snodgrass 2006). Werthmann (2007) explains that the preconceived notion of "*Sedum* = Green Roof" is too simple of an equation for selecting plants that have a great potential to survive and thrive on a green roof. However, *Sedum* is claimed to be the "workhorse" of extensive green roofs (Snodgrass and Snodgrass 2006). Many varieties are groundcovers resistant to drought, disease, and heat. According to Stephenson (1994), a primary reason that varieties of *Sedum* are so successful on green roofs is because they are crassulacean acid metabolism (CAM) plants. The CAM process thrives only in instances of restricted water availability (Snodgrass and Snodgrass 2006, Preece 2005). Monterusso et al. (2005) evaluated seven varieties of *Sedum* and their response to water availability. The second year after establishment, all the supplemental irrigation was removed and the plants grew sufficiently with only rainwater as their moisture source; moreover, 100 % of the *Sedum* survived even after the supplemental water was removed. *Sedum's* ease of propagation also contributes to their high success rate on the roof. *Sedum* can be propagated by simply breaking off tops of the plant and spreading them on the green roof medium to fill in bare spots (Cooper 2010). Along with *Sedum*, wild flowers, native plants, and grasses are among the many plants that are utilized to gain aesthetic appeal and functionality on a green roof (Snodgrass and Snodgrass 2006). Tallamy (2007) indicated that suburbia needs to restore native species and biodiversity for the future. The challenge on a green roof is to develop the best practices for propagation, planting, and maintenance of plants, which in turn, have high survivability, durable, functional, and aesthetic.

Green roof plants are typically established by one of six different methods: seeds, cuttings, plugs, nursery containers, vegetated mats, and module trays (Snodgrass and Snodgrass

2006). Nursery containers, vegetative mats, and modules are grown as individualized containers and placed on a green roof; whereas seeds, cuttings, and plugs can be directly established into the green roof medium. According to Getter and Rowe (2007), plugs have an existing root system that gives them an advantage over using seeds and cuttings. However, plugs often have problems with their roots establishing in the green roof medium. Plugs are typically grown in a peat-based medium that is high in organic matter and nutrients (Werthmann 2007). Furthermore, plants grown in containers need to have their roots cut to avoid roots growing in a circle around the interior of the pot and maintaining that shape after planting (Watson 1996, Watson and Clark 1996). Slow growth is another factor of transplanting, and will increase again once the roots start to regenerate. Adequate water is a key factor in regeneration, although there are other limitations such as nutrients, light, and temperature. Given the typical low organic matter, nutrients, and water supply on green roofs, it is important to find methods to establish plugs quickly in a green roof medium in order for them to survive (Koehler 2010). Getter and Rowe (2007) found that *Sedum* plugs planted in spring had an 81 % survival rate compared to a 23% survival rate in an autumn planting. The spring plugs had 16 weeks to establish, while the autumn plugs had less than five weeks to establish before the onset of winter weather. Consequently, due to freezing and thawing action, many plugs heaved out of the medium exposing the roots. The cold exposure, an unheated rooftop, and lack of hardiness in extreme conditions were possible reasons for the plants' death. This emphasizes the advantage of plant roots being established into the green roof medium before harsh winter seasons.

Components of green roof medium. Plant selection is important, but equally important is the medium. There are numerous medium mixes available for green roofs with differing component ratios based on the types of plants to be grown. Common base materials include lightweight aggregate, shale, or slate with different sources of organic material. Germany developed the Forschungsgeesllschaft Landschaftsentwicklung Landschaftbau (FFL)-Guidelines, which has, in their opinion, the best combination of compost to lightweight aggregate. Germany has been using these guidelines since 1975 and are far more advanced in their understanding of green roof media than in North America (Philippi 2002). However, their standards are not appropriate to the diverse and harsh environments of the United States and Canada. The FLL's regulations has been interpreted as a "loose" standard because in Germany compost is not as widely available as it is in the United States. Since compost materials are more readily available in North America, there should be more companies producing green roof materials, but this is not the case (DiNorsica and Buist 2009, Yepsen 2009). American Standard Testing Methods (ASTM) is the North American system that defines the best materials for specific areas based upon climate and available resources. The ASTM standards are expanding the norms of the green roof industry in North America, so that each region can use local materials including brick, lightweight aggregate, and compost instead of transporting them across the country (Beattie and Berghage 2001, Yepsen 2009, Mather 2006). Thus, this should allow for the use of regional materials, such as vermicompost, to provide more opportunities for new construction of green roofs to earn LEEDS points.

Because of environmental differences, the FFL and ASTM have not developed a definitive percentage of organic matter recommended in a green roof medium. Mather (2006) indicates that approximately 20% organic matter to 80% inorganic matter had the best plant growth response on the eastern side of United States of America. The organic matter in green roof media can be made up of many different materials, but quality compost and vermicompost have become popular due to their water holding capacity, nutrient content, and degradation of pollutants (Alexander 2004). There are many different types of vermicompost and research is currently being conducted world-wide with this material.

Vermicomposting occurs when earthworms feed on decomposing organic waste in a controlled manner (Orozco et al. 1996). Numerous organic materials can be used to produce vermicompost. For example, coffee grounds and vegetable wastes are often used as the base organic material to produce vermicompost at the Southern Illinois University of Carbondale Vermicompost Center (Vigardt 2012). Adi and Noor (2008) found that worms in coffee compost had a higher weight due to better aeration, fungal appearance, and volatile compounds which also kept the pests away compared to kitchen compost; furthermore, coffee ground compost and the combination of coffee grounds and kitchen waste had higher nutritional value than the kitchen compost alone with the exception of calcium and phosphorus.

Other materials for green roof media. According to Sutton (2008), mycorrhizae, in addition to organic matter, can potentially improve nutrient availability in green roof environments. Mycorrhizae are fungi that live symbiotically with plant roots in many soil types (Brady and Weil 2008). They have developed relationships over time with many plant species. The fungus penetrates into the plant's roots and later grows down into the soil. The mycorrhizae, acting like extensions of the roots, have mycelia that absorb nutrients and moisture from the soil supplying the nutritional needs of the host plant (Dr. Earth Inc. 2012). Sutton (2008) found that mycorrhizae can be an important part of maximizing the growth of native plants and grasses. Mycorrhizae could benefit green roof plants by helping them absorb nutrients and moisture which can be scarce in many green roof environments.

While there has been significant research conducted determining plant species most suitable for green roof media, little research has focused on the propagation medium used in green roof plant production. Since establishment is vital to plug survival on a green roof, this research was initiated to determine whether plants were able to germinate and grow well with different media verses peat. This research had two objectives: 1) quantify the germination rates for four plant species grown in different base media applied with fertility treatments 2) compare the growth rate of these four plant species plants with different base media and fertility treatments. The purpose of this research was to evaluate four green roof plants propagated by seeds in different base media receiving different fertility treatments. The specific objectives were to determine if germination rates and plant size (in the plug stage) were influenced when propagated in lightweight aggregate medium versus greenhouse medium receiving fertilizer treatments. The specific fertilizer treatments were: fertilizer, double fertilizer, vermicompost, mycorrhiza, and green roof mix. The fertilizer treatment was applied once per week with 20N-20P- 20K (JR Peters Inc, Allentown, PA). The double fertilizer treatment was applied twice per week with 20N- 20P- 20K. The vermicompost was obtained from the SIUC Vermicompost Center and mixed with a 1:1 ratio with the peat based greenhouse medium and lightweight aggregate medium (referred to as the base media). The mycorrhizae were donated by BioGreen LLC (Volo, IL) and applied at 5.96 kilograms per cubic meter. The green roof mix was mixed at a 1:1 ratio with each base medium.

CHAPTER 2

PLANT GROWTH WITH DIFFERENT MEDIA FOR GREENHOUSE PLANTING

ABSTRACT

Extensive green roofs have harsh growing conditions, and establishment in these conditions can be difficult. Although research shows that establishing a solid root system on an extensive green roof is vital for the plug survival, there is little research on the plug medium itself. This experiment was conducted over two years (2011-2012) and evaluated the germination and growth rates of four plants (*Allium schoenoprasum* L., *Dianthus gratianopolitanus 'Grandiflorus'* Vill, *Sedum kamtschaticum* Fisch. & C.A. Mey. Spp. *ellacombianum* Praeger R.T. Culausen, and *Talinum calycinum* Engelm.) in either a peat based greenhouse medium or a lightweight aggregate medium amended with five fertility treatments (Fertilizer once per week, two applications of the fertilizer per week, vermicompost at 1:1 ratio, mycorrhizae applied at 5.96 kg per cubic meter, and a green roof mix at 1:1 ratio).

Seeds propagated in the greenhouse base medium had higher germination rates verses seeds grown in the lightweight aggregate medium base. The greenhouse base medium seedlings grew much larger and heavier in size regardless of plant species. In some cases, the data from the base medium was not significant in growth (although the greenhouse medium tended to always have higher values), but the addition of all fertility treatments affected much of the observed plant growth.

In the germination study, seeds tended to have a higher germination rate in the greenhouse base medium than the lightweight aggregate medium base for all plants, although the *Sedum* seeds were the only seeds that differed significantly between the two base medium. When the fertility treatments were taken into consideration, the germinated seeds indicated significant

differences with *Dianthus* and *Talinum* in the greenhouse medium and *Allium, Dianthus, Sedum*, and *Talinum* in the lightweight aggregate. The control group consists of the control, fertilizer, and double fertilizer because soluble fertilizer was not applied until a month into this study. The control yielded the highest germination in both base media. The green roof mix had high germination rates, for three species excluding *Talinum*, in both base media and offers the potential to be added to future green roof plugs.

In the growth study, the greenhouse medium always had larger and heavier plants compared to the lightweight aggregate. The fertility treatments of vermicompost, mycorrhizae, and green roof typically lessened the growth rates of all four plant species evaluated in the greenhouse base medium. However, the lightweight aggregate medium showed increased growth rates for all four plant species with all applied fertility treatments. The green roof mix as a fertility source used with the greenhouse base medium showed the greatest potential for use in plugs. Although this combination was lower than the most of the other greenhouse based media, it provided consistent average growth in the experiment.

INTRODUCTION

Extensive green roofs provide many benefits to urban landscapes including: less storm water runoff, decrease in water pollution, energy conservation, decrease in urban heat island effect, and sound reduction (Getter and Rowe 2006, Beattie and Berghage 2001, Scholz-Barth 2001). The plants that grow on these extensive green roofs are often exposed to extremely harsh conditions such as a shallow mineral based medium that has little organic matter to provide nutrients or water, as well as weather conditions that are windy, extremely hot in the summer or cold in the winter (Alexander 2004, Monterusso et al. 2005). Due to these limitations, different types of organic matter, plant species, and sowing styles are being evaluated to optimize growth and sustainability on extensive green roofs.

Many cities across the United States are requiring buildings to have LEEDS (Leadership in Energy and Environmental Design) certifications on new buildings (Richards 2012). A major component of LEEDS is sourcing materials. LEEDS user guide (2014) states that building materials should come from within a 100-mile radius for purchase and distribution. Thus, this requires experimentation with materials that are not always found on each green roof which may be found in certain regions. Lightweight aggregate is the most common medium used on green roofs, but research on other lightweight media is being evaluated (Elstein et al. 2008, Emilsson 2008). Aside from the structural porous base of green roof media, research on organic matter is also being conducted.

Organic matter on a green roof is essential for plant life because it provides nutrients and moisture (Alexander 2004). However, green roofs should not have too much organic matter due to weight restrictions and an abundance of organic matter can provide excessive growth which can be detrimental to a green roof during drought (Getter and Rowe 2006). There is no definitive percentage of organic matter required in a lightweight medium for green roof media, but Mather (2006) indicates that 20% organic matter in a green roof medium had the best plant growth response. Deciding the type of organic matter to place in a green roof medium is often based on what is available in a particular region because of LEEDS (DiNorsica and Buist 2009, Yepson 2009). Quality compost and vermicompost have become popular choices on a green roof for organic matter because of their ability to hold water, nutrients, and allow for the degradation of pollutants (Alexander 2004). Vermicomposting, the decomposition of organic waste via earthworms, has many different base components such as coffee grounds, leaves, and food waste (Orozco et al. 1996, Adi and Noor 2008, Vigardt 2012).

Mycorrhizae have the potential to increase plant nutrient uptake from soils (Sutton 2008) Mycorrhizae are fungi that have a symbiotic relationship with plant roots to increase the area for nutrient absorbtion (Brady and Weil 2008). This relationship can increase amount of water and nutrients a plant is able to absorb, which could relate to increased survival on a harsh green roof.

While there has been significant research on green roof media, specifically organic matter, little research has focused on a propagation medium during production. Green roof plants are established either by seeds, cuttings, plugs, nursery containers, vegetated mats, or module trays (Snodgrass and Snodgrass 2006). Seeds, cuttings, and plugs are directly sown into the existing green roof medium, whereas nursery containers, vegetative mats, and module trays come pre-fabricated and placed on top of the roof. Although plugs have an advantage over seeds and cuttings because of their root system, root establishment into the green roof medium can be problematic (Getter and Rowe 2007). Since plugs are typically grown in a peat-based medium high in organic matter, moisture becomes vital to plug survival. If there is not enough water available, the medium becomes hydrophobic and can repel the already scarce water. Temperature fluctuation can also cause plugs to heave out of the green roof medium in the winter months (Getter and Rowe 2007). Besides the harsh environment on green roofs, plugs also suffer from animal damage, particularly birds that pull plugs out of the medium in search of insects (Werthmann 2007).

MATERIALS AND METHODS

This study was conducted in the College of Agricultural Sciences Teaching Greenhouse on the Southern Illinois University (SIU) campus in Carbondale during 2011 and 2012. The location was secluded in the northeast facing Range 199a. The range was cleaned and sanitized with a Physan 20™ (Tustin, CA) wash prior to the research.

This study was initiated on February 5, 2011 and repeated February 7, 2012. The study was set up as a 2x6 split-split-plot design in a randomized complete block with 3 replications (Figures 1, 2, and 3). The main plots were the greenhouse base medium and lightweight aggregate medium. The split plots were the fertilizer treatments which included fertilizer, double fertilizer, vermicompost, mycorrhiza, and green roof mix; while the split-split plots were the four plant species. These four plant species were: *Allium schoenoprasum, Dianthus gratianopolitanus*, *Sedum kamtschaticum 'ellacombianum',* and *Talinum calycinum* (later referenced by their first genus, *Allium, Dianthus, Sedum,* and *Talinum*). The greenhouse medium used was a standard mix processed in the SIUC Teaching Greenhouse (Table A). The light weight aggregate medium and the green roof mix were purchased from Midwest Trading Company in Maple Park, Illinois. The vermicompost was obtained from the SIUC University Farms Sustainability Center at the Vermicompost Center and generated from coffee grounds obtained from Starbucks at the SIUC Student Center. The mycorrhizae were obtained from BioGreen (Volo, Illinois).

Base Media												
Replication A	Treatment		Treatment		Treatment		Treatment		Treatment		Treatment	
Media Type	Vermi	Vermi	Control	Control	Greenroof	Greenroof	Dbl Fertilizer	Dbl Fertilizer	Mycro	Mycro	Fertilizer	Fertilizer
Aggregate	TALINUM	SEDUM	SEDUM	DIANTHUS	ALLIUM	DIANTHUS	SEDUM	TALINUM	DIANTHUS	ALLIUM	ALLIUM	TALINUM
Aggregate	ALLIUM	DIANTHUS	ALLIUM	TALINUM	TALINUM	SEDUM	ALLIUM	DIANTHUS	SEDUM	TALINUM	DIANTHUS	SEDUM
Greenhouse	DIANTHUS	TALINUM	DIANTHUS	ALLIUM	TALINUM	DIANTHUS	SEDUM	ALLIUM	TALINUM	DIANTHUS	SEDUM	TALINUM
Greenhouse	ALLIUM	SEDUM	SEDUM	TALINUM	SEDUM	ALLIUM	TALINUM	DIANTHUS	ALLIUM	SEDUM	ALLIUM	DIANTHUS
Replications B	Dbl Fertilizer	Dbl Fertilizer	Greenroof	Greenroof	Mycro	Mycro	Fertilizer	Fertilizer	Vermi	Vermi	Control	Control
Aggregate	SEDUM	ALLIUM	DIANTHUS	SEDUM	ALLIUM	SEDUM	SEDUM	TALINUM	ALLIUM	DIANTHUS	TALINUM	ALLIUM
Aggregate	TALINUM	DIANTHUS	ALLIUM	TALINUM	DIANTHUS	TALINUM	DIANTHUS	ALLIUM	TALINUM	SEDUM	DIANTHUS	SEDUM
Greenhouse	SEDUM	ALLIUM	SEDUM	DIANTHUS	ALLIUM	SEDUM	TALINUM	ALLIUM	SEDUM	ALLIUM	DIANTHUS	TALINUM
Greenhouse	DIANTHUS	TALINUM	TALINUM	ALLIUM	TALINUM	DIANTHUS	DIANTHUS	SEDUM	DIANTHUS	TALINUM	SEDUM	ALLIUM
Replication C	Fertilizer	Fertilizer	Vermi	Vermi	Control	Control	Greenroof	Greenroof	Dbl Fertilizer	Dbl Fertilizer	Mycro	Mycro
Greenhouse	TALINUM	SEDUM	ALLIUM	TALINUM	SEDUM	ALLIUM	SEDUM	ALLIUM	SEDUM	TALINUM	ALLIUM	DIANTHUS
Greenhouse	DIANTHUS	ALLIUM	SEDUM	DIANTHUS	DIANTHUS	TALINUM	DIANTHUS	TALINUM	DIANTHUS	ALLIUM	SEDUM	TALINUM
Aggreagate	SEDUM	ALLIUM	TALINUM	ALLIUM	ALLIUM	TALINUM	ALLIUM	DIANTHUS	ALLIUM	TALINUM	SEDUM	ALLIUM
Aggreagate	TALINUM	DIANTHUS	DIANTHUS	SEDUM	DIANTHUS	SEDUM	TALINUM	SEDUM	DIANTHUS	SEDUM	TALINUM	DIANTHUS
	KEY											
	Main Plot		Split Plot		Split Split Plot							
	100's Place - Base Medium		10's Place - Fertility Treatment		1's Place - Plant Species		Replications					
	100 Greenhouse		10 Control		1 Allium		A					
	200 Lightweight Aggregate		20 Fertilizer		2 Dianthus		B					
			30 Double Fertilizer		3 Sedum		C					
			40 Vermicompost		4 Talinum							
			50 Mycorrizae									
			60 Green Roof									

Figure 1. Green roof plug study 2x6 split-split plot design set up

Base Media												
Replication A	Treatment		Treatment		Treatment		Treatment		Treatment		Treatment	
Media Type	4	4	1	1	6	6	3	3	5	5	2	2
Aggregate	244a	243a	213a	212a	261a	262a	233a	234a	252a	251a	221a	224a
Aggregate	241a	242a	211a	214a	264a	263a	231a	232a	253a	254a	222a	223a
Greenhouse	142a	144a	112a	111a	164a	162a	133a	131a	154a	152a	123a	124a
Greenhouse	141a	143a	113a	114a	163a	161a	134a	132a	151a	153a	121a	122a
Replications B	3	3	6	6	5	5	2	2	4	4	1	1
Aggregate	233b	231b	262b	263b	251b	253b	223b	224b	241b	242b	214b	211b
Aggregate	234b	232b	261b	264b	252b	254b	222b	221b	244b	243b	212b	213b
Greenhouse	133b	131b	163b	162b	151b	153b	124b	121b	143b	141b	112b	114b
Greenhouse	312b	134b	164b	161b	154b	152b	122b	123b	142b	144b	113b	111b
Replication C	2	2	4	4	1	1	6	6	3	3	5	5
Greenhouse	124c	123c	141c	144c	113c	111c	163c	161c	133c	134c	151c	152c
Greenhouse	122c	121c	143c	142c	112c	114c	162c	164c	132c	131c	153c	154c
Aggreagate	223c	221c	244c	241c	211c	214c	261c	262c	231c	234c	253c	251c
Aggreagate	224c	222c	242c	243c	212c	213c	264c	263c	232c	233c	254c	252c
	KEY											
	Main Plot		Split Plot		Split Split Plot							
	100's Place - Base Medium		10's Place - Fertility Treatment		1's Place - Plant Species		Replications					
	100 Greenhouse		10 Control		1 Allium		A					
	200 Lightweight Aggregate		20 Fertilizer		2 Dianthus		B					
			30 Double Fertilizer		3 Sedum		C					
			40 Vermicompost		4 Talinum							
			50 Mycorrizae									
			60 Green Roof									

Figure 2. Green roof plug study 2x6 split-split plot design numerical coding

a	Greenhouse	Control	*Allium*	111a
a	Greenhouse	Control	*Dianthus*	112a
a	Greenhouse	Control	*Sedum*	113a
a	Greenhouse	Control	*Talinum*	114a
a	Greenhouse	Fertilizer	*Allium*	121a
a	Greenhouse	Fertilizer	*Dianthus*	122a
a	Greenhouse	Fertilizer	*Sedum*	123a
a	Greenhouse	Fertilizer	*Talinum*	124a
a	Greenhouse	D. Fert	*Allium*	131a
a	Greenhouse	D. Fert	*Dianthus*	132a
a	Greenhouse	D. Fert	*Sedum*	133a
a	Greenhouse	D. Fert	*Talinum*	134a
a	Greenhouse	Green Roof	*Allium*	161a
a	Greenhouse	Green Roof	*Dianthus*	162a
a	Greenhouse	Green Roof	*Sedum*	163a
a	Greenhouse	Green Roof	*Talinum*	164a

Figure 3. Example of green roof plug study numerical code organization

Table A. SIUC Greenhouse medium recipe

Components	**Amount**
4 cubic feet bag Peat Moss	2 Bags
4 cubic feet bag of Vermiculite	1 Bag
4 cubic feet bag of Perlite	1 Bag
Agricultural Lime	14 LBS
Superphosphate 0-45-0	281g
Calcium Nitrate	320g
Trace Elements	79g
Sequestrene Iron	54g
Granular Wetting Agent	170g

Directions

In a soil mixer break apart peat moss until fine

Apply water until it is able to hold shape, but does not ring out water

In a separate 3-gallon container, fill half with vermiculite and add the wetting agent. Mix well

Mix in the rest of Vermiculite bag and perlite the whole perlite bag by applying evenly along the opening of the soil mixer

Apply the 3 gallon mix of vermiculite and wetting agent

Add the Lime, Superphosphate, Calcium, Trace Elements and Iron evenly

After mixing is complete, open soil mixer into soil crate and place in steam room

Seal steam room door and turn on

Steam soil until 82 °C is reached; time often varies so check often

Turn off and let cool before opening door and removing soil crate

Plant selection. The four plants chosen for this research were *Allium schoenoprasum* L., *Dianthus gratianopolitanus ‘Grandiflorus’* Vill, *Sedum kamtschaticum* Fisch. & C.A. Mey. Spp. *ellacombianum* Praeger R.T. Culausen, and *Talinum calycinum* Engelm. Seeds were purchased from Jelitto Staudensamen Perennial Seeds (2012), a German based company with a location in Louisville, Kentucky. These four plant species exhibited different structural and physiological components; two photosynthetic pathways (C3 and CAM), a variety of leaf sizes, growth habits, and flowering periods.

Allium schoenoprasum L. (chives) is a zone 4 bulb commonly used on a shallow medium green roof. It has green foliage that lasts throughout the spring and summer seasons, which is uncommon for bulbs (Dunnett and Kingsbury 2008). Its pink flowers bloom in the late spring, and attracts bees and other wildlife (Werthmann 2007). *Allium schoenoprasum* grows approximately 25 cm tall with a 15 cm spread. This plant has the ability to self-sow, but it is slow to establish from seed (Dunnett and Kingsbury 2008). One of the attractive features of chives is its use for consumption in restaurants and home cooking, so growing this plant can help support urban sustainability in purchasing local produce (Snodgrass and Snodgrass 2006).

Dianthus gratianopolitanus ‘Grandiflorus’ Vill. (*Dianthus g.g.* or Cheddar Pink) is an herbaceous plant often used in rock gardens and is hardy to -40°C, and tend to readily adapt to green roof enviornments (Still 2004). This cultivar grows 20 to 25 cm tall with equal spread (Mineo 1999). The greatest appeal of this particular plant is its aesthetics. It blooms in the late spring or early summer with large pink flowers (Still 2004). The foliage varies from shades of green, blue, and gray plus the added change of texture (Dunnett and Kingsbury 2008, Still 2004). *Dianthus* uses the Calvin cycle (C_3) for CO_2 uptake (Avelange Sarrey & Rébillé 1990). Typical of all herbaceous plants, *Dianthus* dies back each year, which is important for a green roof since "plants on a green roof should produce their own compost, with dead leaves and a natural turnover of organic material - creating an equilibrium" (Yepsen 2009). However, since *Dianthus* only lives for about five years on the green roof, a maintenance plan should be established (Snodgrass and Snodgrass 2006, Snodgrass and McIntyre 2010).

Sedum kamtschaticum Fisch. & C.A. Mey. Spp. *ellacombianum* (Praeger) R.T. Clausen is a plant species that has survived on the Michigan State green roof. It grows approximately 15 cm tall with a 20 cm spread. This plant has aesthetic appeal due to its showy yellow flowers and pale greenish yellow foliage. Unlike many other *Sedum* species, *S. kamtschaticum* performs poorly as a ground cover because the growth habit is tall and not compact (Snodgrass and Snodgrass 2006, Still 2004). *S. kamtschaticum* uses a photosynthetic process call CAM-cycling or facultative CAM, which has both C_3 and CAM characteristics. CAM-cycling starts by fixing CO_2 similar to C_3 plants during daylight, but once darkness falls, stomata close and malic acid builds up in the plant tissue. Daylight causes the stomata to open which allows the CO_2 to enter again to be processed and the acids in the plant tissue slowly decreases (Martin et al. 1988, VanWoert 2005).

Talinum calycinum Engelm. (Synonyms: *Phemeranthus calycinus* Engelm. Kiger and largeflower flameflower) is a petite succulent plant that also adds aesthetic appeal to green roofs (Snodgrass and Snodgrass 2006). This plant is typically found in the rocks and crevices of its natural habitat and only stands 10 cm tall. It has bold pink flowers with stalks roughly 20 to 25 cm tall, and typically blooms from midsummer to mid-autumn, which is when many other plant species found on green roofs are no longer flowering (Mohlenbrock 2001, Snodgrass and Snodgrass 2006). *Talinum* uses C_3 or CAM-cycling during the uptake of CO_2 and utilizes CAM-idling in stressful circumstances. CAM-idling is the ability to close the stomata in both daylight and darkness to preserve water (Martin et al. 1988, Martin and Zee 1983). It is native to the southern Midwest and further south into Texas (USDA 2012). Honey bees and other wildlife are attracted to *Talinum*, making this plant an asset for green roof biodiversity. Hardy to -23°C, it is used as an annual in colder climates. *Talinum* is self-sowing and once itss foliage dies back in the fall, it will disperse seeds in the nearby surrounding areas (Snodgrass and Snodgrass 2006, Werthmann 2007). In a case study at the Headquarters of the American Society of Landscape Architects green roof, the designer included a raised aluminum grate for employees and service people to utilize when walking out onto the roof. Plants were grown under the aluminum grate, which increased the green surface area 30 percent. *Talinum* was the most prominent plant grown in this protected and shaded area with its vivid pink flower stalks growing through the grate (Werthmann 2007).

Medium mixing and sowing. The vermicompost and green roof medium treatments were mixed separately at a 1:1 ratio with the lightweight aggregate medium and greenhouse medium. The mycorrhizal inoculum was mixed with the associated base medium (equivalent to 5.96 kg per cubic meter). The black plastic plug trays used had 32 cells, each cell was 3.81cm wide by 7.62cm deep. The tray cells were filled with the appropriate medium, labeled, and placed on a greenhouse bench. Additionally, a sample of each treatment with associated base medium was collected and analyzed by Brookside Laboratories Inc. (New Knoxville, OH). Selected nutrient properties of each growth medium and treatment are summarized in Tables 1 through 4. Following positioning of the trays in the greenhouse, seeds of the four plant species were sown. Seeds were misted for one month, and then watered daily until the end of the experiment. The fertilizer treatment, 20N-20P- 20K (JR Peters Inc, Allentown, PA), was applied once per week, while the double fertilizer treatment was applied twice per week.

The experiments were terminated on May 5, 2011 and May 7, 2012. Final plant height and width (for *Allium* leaf count) measurements were collected and recorded. The medium was removed from the roots and fresh biomass was recorded. Each plant was placed into a numerical coded brown paper bag then dried in a Humboldt Dryer (Elgin, IL) and set to 65°C to dry for 1 week. After the plants were removed, dry biomass was measured and recorded before being discarded.

The data was analyzed using a JMP distribution of Y by X, showing significant differences for ChiSquare when $P < 0.05$. Germination percentages were also analyzed for each base medium, with and without the presence of treatments. The height, weight (or leaf count for *Allium*), and biomass was calculated using a fit model to determine if there were significant differences using the Student's T-Test. These variables were run as the base medium was the split plot and treatment as the split-split plot. The plant species were analyzed separately using JMP Statistical Discovery Software (Cary, NC).

Table 1. Greenhouse and lightweight aggregate medium analysis used in green roof plug experiment for 2011.

Medium	pH	S (ppm)	P [y] (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	K^{+} (ppm)	Na^{+} (ppm)
100 GH	5.3	18	52	827	124	29	36
140 GH + V	5.8	121	324	5624	581	1644	182
150 GH + M	5.6	46	78	964	171	66	55
160 GH + GR	6.4	18	88	923	157	59	38
200 LWA*	7.8	16	28	488	84	67	26
240 LWA + V	6.4	98	457	7763	739	2922	246
250 LWA + M	6.9	83	88	1366	170	233	57
260 LWA + GR[z]	7.6	17	76	753	137	78	33

100 GH: Greenhouse medium only
140 GH + V: Greenhouse medium with vermicompost 1:1
150 GH+ M: Greenhouse medium with mycorrhizae 5.96 kg/ cubic meter
160 GH+ GR: Greenhouse medium with green roof medium 1:1
200 LWA: Lightweight aggregate medium only
240 LWA+ V: Lightweight aggregate medium with vermicompost 1:1
250 LWA+ M: Lightweight aggregate medium with mycorrhizae 5.96 kg/cubic meter
260 LWA+ GR: Lightweight aggregate medium with green roof medium 1:1
* Calculated from 2012 LWA results, since it came from the same container
[z] Assuming the lightweight aggregate medium is the same as the year 2012
[y] Mehlich III used to test for Phosphorous

Table 2. Greenhouse and lightweight aggregate medium analysis used in greenhouse plug experiment for 2011 (Continued)

Medium	C/N Ratio	CEC (meq/100cc)	OM (%)	Ca^{2+} (%)	Mg^{2+} (%)	K^{+} (%)	Na^{+} (%)	NH_4^{+} (%)	H^{+} (%)	% Base Saturation
100 GH	49.8	9.4	56.1	43.8	11.0	0.8	1.7	6.8	36.0	64
140 GH + V	11.2	51.9	35.7	54.2	9.3	8.1	1.5	5.8	21.0	79
150 GH + M	29.8	10.0	55.6	48.4	14.3	1.7	2.4	6.2	27.0	73
160 GH + GR	ND	8.4	30.0	56.5	16.2	1.9	2.0	5.4	18.0	82
200 LWA*	ND	8.8	0.6	68.7	19.7	4.8	3.2	3.6	0.0	100
240 LWA + V	10.8	62.3	27.0	62.4	9.9	12.0	1.7	5.0	9.0	91
250 LWA + M	<2.0	9.7	1.2	70.6	14.7	6.2	2.6	4.5	1.5	98
260 LWA + GR	ND	5.5	2.3	69.0	20.6	4.0	2.8	3.8	6.0	94

100 GH: Greenhouse medium only
140 GH + V: Greenhouse medium with vermicompost 1:1
150 GH+ M: Greenhouse medium with mycorrhizae 5.96 kg/ cubic meter
160 GH+ GR: Greenhouse medium with green roof medium 1:1
200 LWA: Lightweight aggregate medium only
240 LWA+ V: Lightweight aggregate medium with vermicompost 1:1
250 LWA+ M: Lightweight aggregate medium with mycorrhizae 5.96 kg/ cubic meter
260 LWA+ GR: Lightweight aggregate medium with green roof medium 1:1
* Calculated from 2012 LWA results, since it came from the same container
[z] Assuming the lightweight aggregate medium is the same as the year 2012
ND – No C/N ratio was submitted for analysis in 2011

Table 3. Greenhouse and lightweight aggregate medium analysis used in green roof plug experiment for 2012

Medium	pH	S (ppm)	P [z] (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	K^{+} (ppm)	Na^{+} (ppm)
100 GH	5.5	50	95	1778	163	40	40
140 GH + V	6.3	31	211	1589	369	1136	85
150 GH + M	7.6	279	309	1814	327	736	106
160 GH+ GR	6.4	74	250	3691	351	234	50
200 LWA	7.8	16	28	488	84	67	26
240 LWA + V	7.3	10	278	1648	639	2354	140
250 LWA + M	7.9	204	467	1201	476	1198	131
260 LWA + GR	6.7	35	424	4005	503	507	54

100 GH: Greenhouse medium only
140 GH + V: Greenhouse medium with vermicompost 1:1
150 GH+ M: Greenhouse medium with mycorrhizae 5.96 kg/cubic meter
160 GH+ GR: Greenhouse medium with green roof medium 1:1
200 LWA: Lightweight aggregate medium only
240 LWA+ V: Lightweight aggregate medium with vermicompost 1:1
250 LWA+ M: Lightweight aggregate medium with mycorrhizae 5.96 kg/ cubic meter
260 LWA+ GR: Lightweight aggregate medium with green roof medium 1:1
[z] Mehlich III used to test for Phosphorous

Table 4. Greenhouse and lightweight aggregate media analysis used in green roof plug experiment for 2012 (Continued)

Media	C/N Ratio	CEC (meq/100cc)	OM (%)	Ca^{2+} (%)	Mg^{2+} (%)	K^{+} (%)	Na^{+} (%)	NH_4^{+} (%)	H^{+} (%)	% Base Saturation
100 GH	25.0	16.6	47.1	53.7	8.2	0.6	1.1	6.4	30.0	70
140 GH + V	34.6	17.0	55.0	46.9	18.1	17.2	2.2	5.1	10.5	90
150 GH + M	25.2	14.7	32.1	61.7	18.5	12.8	3.1	3.8	0.0	100
160 GH+ GR	ND	25.8	37.9	71.5	11.3	2.3	0.8	5.0	9.0	91
200 LWA	4.3	3.6	0.6	68.7	19.7	4.8	3.2	3.6	0.0	100
240 LWA + V	9.6	21.1	29.3	39.1	25.3	28.7	2.9	4.1	0.0	100
250 LWA + M	12.6	14.1	18.6	42.6	28.1	21.8	4.0	3.6	0.0	100
260 LWA + GR	18.0	28.4	24.3	70.6	14.8	4.6	0.8	4.7	4.5	96

100 GH: Greenhouse medium only
140 GH + V: Greenhouse medium with vermicompost 1:1
150 GH+ M: Greenhouse medium with mycorrhizae 5.96 kg/ cubic meter
160 GH+ GR: Greenhouse medium with green roof medium 1:1
200 LWA: Lightweight aggregate medium only
240 LWA+ V: Lightweight aggregate medium with vermicompost 1:1
250 LWA+ M: Lightweight aggregate medium with mycorrhizae 5.96 kg/ cubic meter
260 LWA+ GR: Lightweight aggregate medium with green roof medium 1:1
ND – No C/N Ratio was submitted for the GH/GR in 2012

RESULTS

Germination with different base media. The greenhouse medium had higher (but not significant) germination percentage at 83% than the lightweight aggregate medium at 74% over all plant species. However, significant ($P< 0.05$) germination rates were determined between the lightweight aggregate medium and the greenhouse medium for *Sedum* (Table 5). The percent germination with the greenhouse medium was ten percent more than that of the lightweight aggregate medium. *Allium*, *Dianthus*, and *Talinum* showed no significant interactions between base media.

Table 5. Percent Germination in the Greenhouse and Lightweight Aggregate Base Media

Plants	LWA	GH	Mean Germination
Allium	92	97	95
Dianthus	85	94	90
Sedum [z]	81	93	87
Talinum	39	47	43
Mean	74	83	79

LWA: Lightweight Aggregate Medium
GH: Greenhouse Medium
[z] *Sedum* is significant at $P\leq 0.0241$* using a Student's T-Test

Germination in base media with treatments. The addition of treatments generally decreased the germination rates within the base media. Germination data was taken prior to any fertilizer application, so the data from the control, fertilizer, and double fertilizer treatments were combined into the control. Therefore, the treatments for germination were; the control in both the greenhouse medium at 90% and the lightweight aggregate medium at 85% had the highest germination rates (Tables 6 & 7). The lowest overall germination rates were observed the mycorrhizal and vermicompost treatments, at 52% and 65% respectively, in the lightweight aggregate medium. Results of the green roof fertility treatment suggests its' potential as a recommended amendment to either base media, as the germination rate was 81% in greenhouse medium and 71% in lightweight aggregate medium. The green roof treatment in the greenhouse medium produced a 100% germination rate for *Allium*, *Dianthus*, and *Sedum.* Similarly, *Allium* and *Dianthus* had 100% germination rates in the green roof treatment with the lightweight aggregate medium. *Talinum* germination rates did not respond positively to the green roof treatment in the greenhouse medium. There were significant interactions ($P< 0.05$) between plant species and the various fertility treatments for germination. *Dianthus* and *Talinum* showed significant differences with the greenhouse medium, while significant differences were determined for all plant species for the lightweight aggregate medium.

Allium showed no apparent interactions to the treatments in the greenhouse medium, but did have significant interactions ($P< 0.05$) to the treated lightweight aggregate medium (Tables 6 and 7). *Allium* showed a germination rate of 100 percent in the control, vermicompost, and green roof treatments in the greenhouse medium. The only treatment that did not germinate 100 percent with the greenhouse medium was the mycorrhizal treatment, germinating at 83 percent. Significant interactions ($P< 0.05$) were demonstrated by *Allium* to the treated lightweight aggregate medium. The control and green roof treatments had a germination rate of 100 percent. *Allium* in the vermicompost and mycorrhizal treatments germinated rates of 83% and 67% respectively.

Dianthus showed significant differences ($P< 0.05$) to the treatments added to both base media (Tables 6 and 7). In the greenhouse medium, *Dianthus* had a 100% germination rate for control, vermicompost, and green roof treatments. The mycorrhizal treatment had a 67% germination rate, which was low enough to make the interaction significant. The lightweight aggregate medium produced a 100% germination rate for Dianthus with only the green roof treatment. The control was expected to show a germination rate at 100%, but the failure of two plants to show any growth resulted with a 94% germination rate. The vermicompost treatment demonstrated a 75% germination rate, while the mycorrhizal treatment showed 50% germination.

Sedum had significant differences (P< 0.05) with the treated lightweight aggregate medium, but did not have significant interactions for the treated greenhouse medium (Tables 6 and 7). There was a 100% germination rate for the green roof treatment with the greenhouse medium, and a 75% germination rate for the green roof treatment with the lightweight aggregate medium. Similar to the *Dianthus, Sedum* had 97% germination rates in greenhouse medium and 92% germination in lightweight aggregate medium with the control treatments were not understood. The vermicompost and the mycorrhizal treatments showed germination rates of 92% and 75% respectively with the greenhouse medium (Table 6). *Sedum* did have significant interactions (P< 0.05) with the treated lightweight aggregate medium, where the vermicompost treatment had 83% germination and the mycorrhizal treatment had 50% germination (Table 7).

Talinum had significant differences (P< 0.05) to the treated greenhouse medium and treated lightweight aggregate medium (Tables 6 and 7). For greenhouse medium the highest germination percentage at 64% was associated with the control (Table 6). The remaining treatments with the greenhouse medium had low germination rates: vermicompost at 8% < green roof at 25% < mycorrhizae at 58% respectively. The germination rates for lightweight aggregate medium were numerically lower than the greenhouse medium. The highest germination percentage was 56% with the control. Germination rates for the remaining treatments were also low: green roof at 8% < vermicompost at 17% < mycorrhizae at 42% respectively.

Table 6. Plant germination rates (%) in the greenhouse medium

	Greenhouse Medium				
Plants	Control [z] (110)	Vermicompost (140)	Mycorrhizae (150)	Green Roof (160)	Mean Germinated
Allium	100	100	83	100	97
Dianthus [y]	100	100	67	100	95
Sedum	97	92	75	100	93
Talinum [x]	64	8	58	25	47
Mean	90	75	71	81	83

[z] Germination count was taken prior to fertilizer applications, so control includes the germinated seeds from the fertilizer treatments.
[y] Rates are significant when χ^2=15.620 for *Dianthus* with Treatments. *Dianthus* is significant with P≤ 0.0014* for P< 0.05
[x] Rates are significant when χ^2=15.818 for *Talinum* with Treatments. *Talinum* is significant with P≤ 0.0012* for P< 0.05

Table 7. Plant germination rates (%) in the lightweight aggregate medium

	Lightweight Aggregate Medium				
Plants	Control [z] (210)	Vermicompost (240)	Mycorrhizae (250)	Green Roof (260)	Mean Germinated
Allium [y]	100	83	67	100	92
Dianthus [x]	94	75	50	100	85
Sedum [w]	92	83	50	75	81
Talinum [v]	56	17	42	8	39
Mean	85	65	52	71	74

[z] Germination count was taken prior to fertilizer applications, so control includes the germinated seeds from the fertilizer treatments.
[y] Rates are significant when χ^2=7.465 for *Allium* with Treatments. *Allium* is significant with P≤ 0.0016* for P< 0.05
[x] Rates are significant when χ^2=15.980 for *Dianthus* with Treatments. *Dianthus* is significant with P≤ 0.0011* for P< 0.05
[w] Rates are significant when χ^2=9.338 for *Sedum* with Treatments. *Sedum* is significant with P≤ 0.0251* for P< 0.05
[v] Rates are significant when χ^2=12.768 for *Talinum* with Treatments. *Talinum* is significant with P≤ 0.0052* for P< 0.05

Height, leaf count, and dry weight comparisons for *Allium*. Allium grown in the base media produced no significant differences in the plant height and dry weight comparing the greenhouse and lightweight aggregate media (Table 8). However, the greenhouse medium data had a significantly higher leaf count ($P < 0.05$) than the lightweight aggregate medium. The addition of the fertilizer, double fertilizer, vermicompost, mycorrhizal, and green roof treatments to the base media also showed significant differences ($P < 0.05$) in plant height, leaf count, and dry weight (Table 9).

Allium showed opposite responses by treatment to the greenhouse and lightweight aggregate media. The vermicompost, mycorrhizal, and green roof treatments often decreased the height, leaf count, and dry weight of the greenhouse grown *Allium*. However, the vermicompost, mycorrhizal, and green roof treatments increased plant height, leaf count, and dry weight for the lightweight aggregate medium. With the exception of the greenhouse medium fertilizer treatment which had the tallest plants (32.2 cm) and most leaves (11 leaves), the greenhouse medium control treatment was significantly higher with an average height of 30.5 cm, a leaf count of 8 leaves per plant, and the greatest weight at 0.94 grams. Within the greenhouse medium, the green roof treatment that had the shortest plants (17.7 cm) and the fewest leaves (4 leaves per plant). The greenhouse medium mycorrhizae treatment produced mixed responses with the lowest plant weight (0.16g), but high plant height (24.6 cm) and leaf count (5 leaves per plant) in the overall results. The lower weight was not expected given the high height and leaf counts.

Although some of the greenhouse medium treatments reduced plant growth, positive responses were observed for the lightweight aggregate medium when treatments were applied. The lightweight aggregate medium control was significantly lower in plant height (9.2 cm), leaf count (3 leaves per plant), and dry weight (0.09 g); however, the lightweight aggregate medium vermicompost treatment produced significantly higher plant height (23.0 cm), leaf count (6 leaves per plant), and biomass (0.47 g).

Table 8. *Allium* height, leaf count, and dry weight associated with the greenhouse and lightweight aggregate base media

Base Media	Means[z]	
Height (cm)		
Lightweight Aggregate	18.1	A
Greenhouse	25.1	A
Leaf Count (#)		
Lightweight Aggregate	4	B
Greenhouse	7	A
Dry Weight (g)		
Lightweight Aggregate	0.29	A
Greenhouse	0.60	A

[z] Means comparing base media for each variable not followed by the same letter are significantly different at $P< 0.05$ in accordance with the Student's T-Test.

Table 9. Least square means of *Allium* by treatment and base medium

Treatments	Lightweight Aggregate Medium Means[z]		Greenhouse Medium Means[z]	
Height (cm)				
Control	9.2	F	30.5	AB
Fertilizer	21.3	CD	32.2	A
Double Fertilizer	22.0	CD	22.9	CD
Vermicompost	23.0	CD	24.0	C
Mycorrhizae	13.8	EF	24.6	BC
Green Roof	18.6	CDE	17.7	DE
Leaf Count (#)				
Control	3	G	8	B
Fertilizer	5	DEF	11	A
Double Fertilizer	4	EFG	7	BC
Vermicompost	6	BCD	6	CDE
Mycorrhizae	3	FG	5	CDEF
Green Roof	5	DEF	4	EFG
Dry Weight (g)				
Control	0.09	E	0.94	A
Fertilizer	0.25	CDE	0.72	AB
Double Fertilizer	0.33	CDE	0.91	A
Vermicompost	0.47	BCD	0.47	BC
Mycorrhizae	0.25	CDE	0.16	DE
Green Roof	0.46	BCD	0.47	BC

[z] Height, leaf count, and total dry weight means not followed by the same letter are significantly different P< 0.05 in accordance with the Student's T-Test.

Height, width, and dry weight comparisons for *Dianthus*. Dianthus comparisons expressed significant differences ($P < 0.05$) in height and width in cm at the widest part of the plant, and dry weight between base media (Table 10). Plants grown in lightweight aggregate medium were lower than those grown in the greenhouse medium (height 5.5 cm< 8.8cm, width 6.2 cm< 9.4 cm, and dry weight 0.70 g < 1.45 g).

Significant differences ($P< 0.05$) were also determined with the addition of the fertilizer, vermicompost, mycorrhizal, and green roof treatments to the base media (Table 11). The greenhouse medium fertilizer treatment (single and double applications) had the best overall growth, but was not significantly different from the control for plant height and weight. The tallest plants were the greenhouse medium mycorrhizal (11.1 cm), fertilizer (Single 11.1 cm and double 9.2 cm applications), and control (10.0 cm) treatments. The greenhouse medium double fertilizer treatment had the widest plants (12.1 cm), but was not significantly different from the single fertilizer application treatment. There were two treatments that had low interactions with the greenhouse medium: vermicompost and green roof medium. The vermicompost had a significantly low weight for the greenhouse medium at 1.05 g, while the green roof medium had a significantly low height at 6.3 cm and width at 8.2 cm.

As noted previously, *Dianthus* had significantly lower plant height, width, and weight in the light aggregate medium; however, improved growth for some treatments were observed for plant height and width. The double fertilizer treatment was significantly taller (6.7 cm) than the remaining lightweight aggregate medium treatments while double fertilizer (7.0 cm), single fertilizer (6.4 cm), green roof (7.8 cm), and vermicompost (6.2 cm) treatments had significantly greater plant widths than the control.

Table 10. *Dianthus* height, width, and dry weight associated with the greenhouse and lightweight aggregate base media

Base Media	Means[z]	
Height (cm)		
Lightweight Aggregate	5.5	B
Greenhouse	8.8	A
Plant Width (cm)		
Lightweight Aggregate	6.2	B
Greenhouse	9.4	A
Dry Weight (g)		
Lightweight Aggregate	0.70	B
Greenhouse	1.45	A

[z] Means comparing base media for each variable not followed by the same letter are significantly different at P< 0.05 in accordance with the Student's T-Test.

Table 11. Least square means of *Dianthus* by treatment and base media

Treatments	Lightweight Aggregate Medium Means[z]		Greenhouse Medium Mean[z]	
Height (cm)				
Control	3.9	D	10.0	A
Fertilizer	6.1	CD	11.1	A
Double Fertilizer	6.7	BC	9.2	AB
Vermicompost	5.7	CD	7.6	BC
Mycorrhizae	5.4	CD	11.1	A
Green Roof	5.7	CD	6.3	C
Plant Width (cm)				
Control	4.1	F	9.4	BC
Fertilizer	6.8	DE	11.5	AB
Double Fertilizer	7.0	DE	12.1	A
Vermicompost	6.2	E	8.3	CD
Mycorrhizae	5.9	DEF	9.4	BC
Green Roof	7.8	CDE	8.2	CD
Dry Weight (g)				
Control	0.50	F	1.63	AB
Fertilizer	0.64	EF	2.32	A
Double Fertilizer	1.02	BCDEF	1.67	ABC
Vermicompost	0.63	EF	1.05	CDEF
Mycorrhizae	0.61	EF	1.58	ABCD
Green Roof	0.81	DEF	1.19	BCDE

[z] Height, width, and total dry weight means not followed by the same letter are significantly different P< 0.05 in accordance with the Student's T-Test.

Height, width, and dry weight comparisons for *Sedum*. The greenhouse medium produced a significantly greater plant width and dry weight (P<0.05) than the lightweight aggregate medium (Table 12) for the *Sedum*. There were no significant differences (P<0.05) in plant height, between the greenhouse and lightweight aggregate media.

The addition of treatments to base media did not have any significant effect on plant height (P< 0.05), but were significantly different for plant width and dry weight (Table 13). The greenhouse medium fertilizer (single and double applications) and mycorrhizal treatments had significantly greater plant widths. Conversely among the lightweight aggregate medium treatments, the control (1.8 cm) and mycorrhizal (3.7 cm) treatments widths were significantly lower than the remaining treatments. The greenhouse medium double fertilizer treatment was significantly greater for plant dry weight than all other treatments (4.63 g), while the greenhouse medium vermicompost treatment was significantly lower from the control, fertilizer (single and double applications), and mycorrhizal treatments.

Table 12. *Sedum* height, width, and dry weight associated with the greenhouse and lightweight aggregate base media

Base Media	Means[z]	
Height (cm)		
Lightweight Aggregate	3.7	A
Greenhouse	6.8	A
Width (cm)		
Lightweight Aggregate	4.5	B
Greenhouse	10.7	A
Dry Weight (g)		
Lightweight Aggregate	0.53	B
Greenhouse	2.09	A

[z] Means comparing base media for each variable not followed by the same letter are significantly different at P< 0.05 in accordance with the Student's T-Test.

Table 13. Least square means of *Sedum* by treatment and base media

Treatments	Lightweight Aggregate Medium Means[z]		Greenhouse Medium Means[z]	
Height (cm)				
Control	1.5	A	6.9	A
Fertilizer	4.3	A	8.5	A
Double Fertilizer	5.0	A	6.6	A
Vermicompost	4.6	A	6.5	A
Mycorrhizae	2.8	A	7.9	A
Green Roof	4.7	A	5.4	A
Width (cm)				
Control	1.8	F	10.2	B
Fertilizer	5.2	E	15.2	A
Double Fertilizer	5.8	DE	13.0	A
Vermicompost	5.6	DE	7.7	CD
Mycorrhizae	3.7	EF	13.0	A
Green Roof	6.3	CDE	8.3	BC
Dry Weight (g)				
Control	0.11	D	2.20	B
Fertilizer	0.48	D	2.26	B
Double Fertilizer	0.69	CD	4.63	A
Vermicompost	0.59	CD	1.03	CD
Mycorrhizae	0.60	CD	2.24	B
Green Roof	0.87	CD	1.51	BC

[z] Height, width, and total dry weight means not followed by the same letter are significantly different $P < 0.05$ in accordance with the Student's T-Test.

Height, width, and dry weight comparisons for *Talinum*. There were no significant differences ($P < 0.05$) in plant height, width, and dry weight between the greenhouse and lightweight aggregate media (Table 14). However, some significant differences ($P < 0.05$) were observed between treatments for the greenhouse medium (Table 15). The greenhouse medium vermicompost treatment was significantly greater than all other treatments for plant height (11.9

cm). The greenhouse medium mycorrhizal treatment was significantly different in plant width (10.2 cm) versus the fertilizer, vermicompost, and green roof treatments. The control treatment was also significantly different in plant width (8.6 cm) versus the fertilizer and green roof treatments. Significant differences in plant dry weight were also observed where the control and mycorrhizal treatments were greater than that of the fertilizer and green roof treatments. The vermicompost treatment was not significantly different from any greenhouse medium treatment. There were no significant differences among the treatments for the lightweight aggregate medium.

Table 14. *Talinum* height, width, and dry weight associated with the greenhouse and lightweight aggregate base media

Base Media	Means[z]	
Height (cm)		
Lightweight Aggregate	2.5	A
Greenhouse	4.7	A
Width (cm)		
Lightweight Aggregate	3.9	A
Greenhouse	6.7	A
Dry Weight (g)		
Lightweight Aggregate	0.29	A
Greenhouse	0.55	A

[z] Means comparing base media for each variable not followed by the same letter are significantly different at $P< 0.05$ in accordance with the Student's T-Test.

Table 15. Least square means of *Talinum* by treatment and base media

Treatments	Lightweight Aggregate Medium Means[z]	Greenhouse Medium Means[z]
Height (cm)		
Control	1.7 C	5.3 B
Fertilizer	3.3 BC	3.8 BC
Double Fertilizer	1.9 C	3.8 BC
Vermicompost	2.0 BC	11.9 A
Mycorrhizae	1.9 C	5.7 B
Green Roof	4.4 BC	2.8 BC
Width (cm)		
Control	2.6 C	8.6 AB
Fertilizer	4.7 C	5.4 C
Double Fertilizer	5.4 BC	5.1 C
Vermicompost	3.7 C	4.8 BC
Mycorrhizae	2.9 C	10.2 A
Green Roof	4.3 C	3.7 C
Dry Weight (g)		
Control	0.13 B	0.86 A
Fertilizer	0.39 B	0.42 B
Double Fertilizer	0.48 B	0.29 B
Vermicompost	0.10 B	0.26 AB
Mycorrhizae	0.25 B	0.91 A
Green Roof	0.23 B	0.20 B

[z] Height, width, and total dry weight means not followed by the same letter are significantly different $P < 0.05$ in accordance with the Student's T-Test.

DISCUSSION

Germination study. Regardless of plant species, the control (control, fertilizer, and double fertilizer) had the highest germination rates for each base medium. The greenhouse medium control had the highest percent germination in this study. Tables 2 and 4 indicate that the greenhouse medium control had higher organic matter than the lightweight aggregate medium control. The meso/micropores (pores smaller than 0.08 mm) influences the organic matter in seed germination by improving the water holding capacity (WHC) and creating an ideal atmosphere for seed germination: ample moisture, humidity, and surface area for seeds to settle on. The WHC in the lightweight aggregate medium is low due to gravitational flow following watering (Brady and Weil 2008, Styer and Koranski 1997, Styer 2000, Ball 1998). Macropores, which are prevalent in the lightweight aggregate medium, may allow for seeds to fall through crevices; and this is especially the case for *Sedum* which had very small seeds. It was the only plant to have significant differences to the base media. Typically, *Sedum* have the ability to grow in almost all conditions, so it was unexpected that there was a significant difference in germination rates in greenhouse medium verses lightweight aggregate medium (Stephenson 1994). The difference in organic matter content between the greenhouse and lightweight aggregate media is a possible explanation for higher germination rates for seeds sown in the greenhouse medium. The vermicompost, mycorrhizal, and green roof treatments aided in supplying nutrients to seedlings, but may have had an adverse effect to the germination process.

The seeds for *Allium*, *Dianthus*, and *Sedum* germinated better when mixed with the greenhouse medium, but *Talinum* had low germination rates in either base medium. When treatments were applied, germination rates decreased, especially with vermicompost and mycorrhizae. Vermicompost can add many nourishing components to a medium by increasing WHC, CEC (cation exchange capacity), and available nutrients (Edwards et al 2011). However, it can also have a negative effect on plant germination and growth if the vermicompost is more than 50% by volume (Atiyeh et al 2001, Buckerfield 1999, Edwards et al. 2011). In this study, a 50% vermicompost mixture with a greenhouse or lightweight aggregate medium was used in the experiments. In a study by Atiyeh (2001), pig vermicompost was added to a soilless medium to examine the changes in physical properties of the medium. The vermicompost increased the water holding capacity, but also had potential negative effects. The porosity of the medium decreased significantly at 50 and 100% vermicompost by volume. The soilless medium with 50 and 100% vermicompost also had extremely high levels of salt in the medium, possessing electrical conductivity values ranging from 242.0 mS/m to 322.0 mS/m. High electrical conductivity (EC) can be damaging to seedlings (Edwards et al. 2011). In this study, the seedlings had higher germination rates in the vermicompost greenhouse medium than the vermicompost lightweight aggregate medium. This is probably due to more organic matter to absorb the higher concentration of cations (See Table 2). Seedlings are sensitive to high salt concentrations and need well drained soils to leach them out (Ball 1998). In the lightweight aggregate medium, the seeds settled on almost 100% vermicompost as the form of organic matter. In a study by Buckerfield et al. (1999), the germination rate of radishes was less than 50% when there was 100% vermicompost. The vermicompost had poor drainage and inhibited plant germination. They concluded that vermicompost should be added at a later stage of growth, not as a medium to for germinating seeds.

The mycorrhiza treatment had the lowest germination rate in both lightweight aggregate medium and greenhouse media at 52% and 71% respectively (Tables 6 and 7). The mycorrhizal applications were high in Mehlich III sulfur, but excess sulfur does not provide many negative affects to plants (Pandey 2013). The mycorrhizae attach to plant roots of plants and aid in mineral nutrient uptake. However, after a viable plate count evaluation of the mycorrhizae used in this experiment, showed low propagule concentrations (data not presented). This could have resulted from overheating in transportation or storage in hot dry conditions. Mycorrhizae should not be exposed to high amounts of soil sulfur according to the label. The soil analysis in 2012 indicated high sulfur levels. However, the high amounts of sulfur should not affect seed germination. The inert ingredients holding the mycorrhizae may have had a negative effect on seed germination. These ingredients were ground rock, humus, and plant fibers. Adequate moisture should be applied prior to sowing seeds (Styer and Koranski 1997, Styer 2000), and since the inert ingredients were dry at the start, the seeds may have needed additional moisture to swell before mixing with the base media. Future experiments should test mycorrhizal activity to insure a viable product.

The green roof treatment in both base media had higher germination rates than the mycorrhiza and vermicompost, but less than the control. The green roof treatment is a growth medium unlike the vermicompost and mycorrhizae treatments, which are amendments. The objective of including the green roof treatment was to determine its effect on plug establishment on a green roof if similar physical properties were incorporated into the base media. Typically, plugs are started in a greenhouse medium and after established, planted on a green roof. Future research would need to evaluate if this treatment yielded a more rapid establishment on a green roof than standard plugs. In this experiment, seeds were directly sown into media filled plugs. Germination rates indicate that direct sowing worked well for seeds in the greenhouse medium, but was difficult to assess in the lightweight aggregate medium. Since the lightweight aggregate medium had low organic matter content and high macro-pore space, the evaluation and results suggest that some of the seeds many not have germinated due to absence of available water due to gravitational flow.

This research indicates that sowing seeds in the greenhouse medium has higher germination rates than seeds sown in the lightweight aggregate medium in this study. The applied treatments should be added later for plant growth and not prior to seed germination. However, there is potential for sowing seeds directly into a greenhouse medium with a green roof fertility treatment for plugs. Little research has been published on plug propagation for green roofs, and there is a large opportunity to expand on using different base medium and fertility treatments in plug propagation.

***Allium* study**. Base media had little effect on the growth of *Allium* (Table 8) and the only significant difference between the base media was associated with leaf count. *Allium* have the ability to grow under a wide variety of conditions; however, ideal growth on a green roof occurs with a base medium with 10% organic matter (Nagase and Dunnett 2011, Still 2004). At 10 percent organic matter, *Allium* is able to withstand the harsh growing conditions of a green roof, specifically low water exposure. Increasing organic matter exhibits lush growth, but increased organic matter is not always possible on a green roof due to weight constraints and run off. Additionally, exposing Allium to increased organic matter, can be detrimental to a plant in times of drought (Nagase and Dunnett 2011). *Allium* are sensitive to drought conditions. Once water becomes unavailable, the plant will lower its photosynthetic rate thus slowing down its growth. The plant can stop growing and is able to survive up to 200 days without water (Brewster 2008). Water availability could be one reason the plants had significantly higher leaf count (Table 8).

Results indicated that organic matter made a difference in the growth when five treatments were applied to the base media. The greenhouse control, fertilizer, double fertilizer, and vermicompost were among the tallest, highest leaf count, and heaviest plants in the experiment. Surprisingly, the lightweight aggregate medium with vermicompost treatment had a leaf count and dry weight similar to the greenhouse medium with vermicompost. The other Allium grown in the lightweight aggregate medium were not as vigorous in growth. This could be because the lack of organic matter which results in less available water and soluble nutrient absorption. The plants were watered equally each day. Since the greenhouse based plants had more organic matter when watering was complete, they were able to retain some moisture until the next watering. The lightweight aggregate medium was able to grow daily from their watering, but limited by the amount of available water.

***Dianthus* study**. The base media had a significant effect on *Dianthus* growth (Table 10) where significant differences in height, width, and weight was associated with the greenhouse medium. Allwood (1954) states that *Dianthus* propagation require soils that are at least 3 inches deep, have available plant nutrients (preferably manure), and have adequate soil structure for root zone cooling. Allwood also indicates that *Dianthus* thrive in soils that are well drained and incorporates limestone. The formula for the greenhouse medium in this experiment (Table A) contains agricultural lime, nutrients, and organic matter for WHC and meso/micropore space. However, the pH of the greenhouse medium in 2011 (5.3) and 2012 (5.5) indicates that not enough lime was added to suit the desired growing conditions for *Dianthus*. Conversely, as compared to the low lime in the greenhouse medium, the lightweight aggregate medium had a pH of 7, was well drained, and had a low CEC. However, this medium lacked organic matter which allowed nutrients to leach out due to its gravitational flow (Preece and Read 2005).

The addition of treatments to the lightweight aggregate medium increased the overall growth of *Dianthus*, contrasting a decrease in growth with the base greenhouse medium. However, the fertilizer treatments improved the overall growth of the plant, regardless of the base media. Lime was not required to enhance the availability of mineral nutrients via cation exchange (Allwood 1954). Vermicompost did not have a positive effect when combined with the greenhouse medium, due to the availability of mineral nutrients. Soils that are nutrient rich are not ideal for *Dianthus* (Allwood 1954). Hence, excess mineral nutrients available from the vermicompost did not improve plant growth in the greenhouse medium. However, vermicompost improved the overall growth when added to the lightweight aggregate medium by increasing nutrients, WHC, and meso/micropores.

Plants may also take up mineral nutrients via mycorrhizal symbiosis. Although the mycorrhizae showed few responses in this study, some positive effects with the greenhouse medium was observed. The mycorrhizal treatment amended to the greenhouse medium ranked average,first in plant height, third in plant width, and fourth in plant biomass. The lightweight aggregate medium control ranked lower in the experiment than the lightweight aggregate medium mycorrhizal treatment in plant height, width, and biomass.

The green roof treatment provided the most consistent growth in this study. Although the greenhouse medium produced greater plant height, width, and biomass, there were no significant differences in growth. This may be due to the ability of *Dianthus* species to grow in rocky terrain with available nutrients and air circulation (Allwood 1954).

***Sedum* study**. The plants grown in the greenhouse medium were significantly different in plant width and biomass than those grown in the lightweight aggregate medium. Although this species of *Sedum* can obtain plant heights of 8 to 10 cm (Evans 1983; Stephenson 1994), this characteristic may be deceiving because this cultivar has a spreading growth habit. Plant diameter is just as important characteristic as plant height, but biomass provides the most information in terms of overall growth. *Sedum* will grow in all potting media, but adequate drainage is most significant (Stephenson 1994). In the wild, *Sedum* do not compete well with other plant species, which is why they have adapted to growing in rocks and crevices in addition to cracks in driveways. They have also been known to grow in limestone, a location where larger, more invasive plants cannot grow. Stephenson does not recommend growing *Sedum* in peat based media because insects, fungi, and competitive weeds thrive and could damage or choke out the plant. He recommends adding gravel and other rough materials to these mixes to improve drainage and deter the growth of weeds. *Sedum* are relatively healthy plants, but they will sustain injury if overwatered. Although *Sedum* do not require much soil, they do require available nutrients to survive. In the wild they will spread to other areas if the current location is nutrient deficient or has a low nutrient content (Stephenson 1994). In this study the lightweight aggregate medium many not have provided enough mineral nutrients for the plants to thrive. The greenhouse medium did have available mineral nutrients (via fertilizer) and water, however, Stephenson (1994) warns that these soils will change the growth characteristics of *Sedum*.

The addition of the vermicompost, mycorrhizal, and green roof treatments to the base media were significant for plant width and biomass, but not height for *Sedum*. Height is the only growth response in this study where the treatments did not show any significant differences. The treatments did have a similar impact on plant width and biomass. The vermicompost treatment had a negative interaction with the greenhouse medium and was significantly lower than the remaining treatments with the same base medium. Vermicompost allows for more readily available calcium, phosphorous, and magnesium in addition to increasing the WHC of the media (Orozco et al. 1996, Ferreras et al. 2006). Adding vermicompost at rates lower than 50% by volume has a positive effect on plant growth and yield, whereas additions of vermicompost at or above 50% by volume may start to reduce the positive growth effects (Arancon et al. 2011, Arancon et al. 2005, Atiyeh et al. 2002). In this experiment 50% vermicompost may facilitate a high WHC and a soluble salt concentration (EC) due to poor drainage. Lightweight aggregate medium amended with 50% vermicompost represents all of the organic matter that supports root growth. *Sedum* have few soil requirements, and given the highly mineral nutrient content associated with vermicompost, coupled with poor drainage due to meso/micro porosity suppresses plant growth. Further research on vermicompost amendments to soil needs to be conducted on plants with different photosynthetic systems, such as CAM plants, to determine if vermicompost has a negative effect.

With the exception of vermicompost amendment, the greenhouse medium with the green roof amendment had a lower plant width and biomass than the other treatments but not significantly different from most treatments. These results were not expected. Stephenson (1994) recommends adding small rocks to soils (in our situation, base media) when planting *Sedum* to facilitate aeration. The green roof treatment to the greenhouse medium was intended to improve aeration. The reason for the failure of *Sedum* to thrive with this treatment is unknown.

The lightweight aggregate medium control had the lowest values for plant width and biomass in the *Sedum* experiment. Plant biomass was not significantly lower than the other base media and treatments, but the plant width was. The *Sedum* control plants in lightweight aggregate medium were not significantly different from plant widths of the *Sedum* in lightweight aggregate medium treated with mycorrhizae. The control and mycorrhizae treatments (Tables 2 and 4) had low organic matter, which could result in low numerical values in plant width.

***Talinum* study**. Base media were not significant for *Talinum* height, plant width, or biomass (Table 14). *Talinum* is an ideal plant for green roofs because of its ability to self-sow, it functions as an annual in cold regions and as a perennial in warmer climates, and it has the ability to thrive in almost any shallow substrate (Snodgrass and Snodgrass 2006). Previously *Talinum* was considered to be substrate indifferent, although later research determined that its growth was inhibited by limestone (Reinhard and Ware 1989). However, Talinum have the ability to grow naturally in limestone, but prefer soils with a lower pH. *Talinum*'s ability to seed and grow in almost any substrate is a possible reason for not having significant differences between the base media in this experiment.

The addition of treatments to the greenhouse medium favored growth. However, since *Talinum* has the ability to grow in a variety of substrates, it was not as consistent as the *Dianthus* and *Sedum* studies. Plant width and biomass had similar results, while plant height was inconsistent with the biomass. These results demonstrate that the *Talinum* plants that showed a spreading nature had more biomass than the plants that displayed a taller characteristic. *Talinum*'s advantage in growing in multiple substrates is amplified by its ability to change from a C_3 plant to a CAM plant. It undergoes CAM-idling in which, the photosynthetic pathway changes from a C_3 to a CAM physiology, only when under the conditions of severe drought stress. When *Talinum* has available water (such as the greenhouse medium associated with a high WHC) it will process water as a standard C_3 plant. When *Talinum* adapts to the unavailability of water (the lightweight aggregate medium characterized by a low WHC) it can close stomata during both the day and night to conserve water (Martin et.al 1988, Martin and Zee 1983). This adaptation gives *Talinum* an advantage over the other plants described in this study, and allows for more uniform growth under extreme circumstances.

Future recommendations. This research indicates that seeds need to be sown into a form of greenhouse medium and maintained as seedlings until they are ready to be transplanted into larger plugs. Our study indicated that the greenhouse grown pla0nts germinated more and grew larger than the lightweight aggregate medium grown plants (Tables 6, 8, 10, and 12). These results on growth may have changed if the seeds were started in another medium before being transplanted into the plugs. Temperature control may have also affected the germination rates of the planted seeds in both base media. Heating mats were not used to maintain temperature at the recommended 24°C soil temperature (Ball 1998). Germination was not the only difficulty plants had with the lightweight aggregate medium; the majority of plants showed poor growth. The unavailability of water and nutrients, plus a deficiency of organic matter in the lightweight aggregate medium resulted in consistently low growth rates (plant height, leaf count/plant width, and biomass).

The introduction of treatments enhanced growth in the lightweight aggregate medium. However, these same treatments had inconsistent results with the greenhouse medium. Tables 9, 11, 13, and 15 showed that greenhouse medium control consistently produced the top 25% in plant height, leaf count/plant width, and biomass. In the greenhouse medium, the fertilizer treatments aided in plant growth, but the remaining treatments suppressed growth responses. The control for lightweight aggregate medium had the lowest amount of growth. Since the lightweight aggregate medium has a low WHC, organic matter content, and a low availability of mineral nutrients low growth numbers were expected; especially for the control. The fertilizer treatments with the lightweight aggregate medium improved plant growth; additionally, fertilizing twice per week versus one application of fertilizer increased plant growth in all but two exceptions: *Allium* leaf count and *Talinum* plant width. In both cases the difference was not significant. Along with the fertilizer treatments, the remaining treatments also improved plant growth rates in the lightweight aggregate medium.

The green roof treatment showed the most consistent results in this study. Regardless of plant species, base medium, and growth characteristics, the collected data was similar. The addition of this treatment supplied the base media with a component each were missing. The greenhouse medium is the most commonly used medium for plugs (Friedrick 2005, Friedrick 2012), but plants grown in the greenhouse medium may have issues rooting into the aggregate on a roof. The green roof treatment added aggregates to the greenhouse medium and give it potential for faster root establishment. The lightweight aggregate medium has a low organic matter content, low WHC, and low available mineral nutrients. The green roof treatment improved the limitations of the lightweight aggregate by increasing essential medium components. Additional research should be done with adding green roof mixes into plugs and observing how quickly those plants adapt to life on a green roof.

With the addition of further research into green roof material with the greenhouse medium, this study should be expanded. Since the effectivity of vermicompost declines at 50% by volume, the vermicompost treatments should be evaluated at 10, 20, 30, 40, and 50% by volume added to the base media to determine if enhanced plant growth will be achieved. The vermicompost added organic matter to the lightweight aggregate medium, which was essential to support plant growth in this study. This may not be the case if additional research is completed using a green roof medium in place of the lightweight aggregate medium. If green roof medium replaced the lightweight aggregate medium in this study, the base medium might be able to support seed germination and plant growth without the need of any fertilizer treatments.

CONCLUSION

Results of this study indicated that the highest germination and growth rates of seeds propagated and grown were in the greenhouse medium compared to those in lightweight aggregate medium. This may be explained due to the lightweight aggregate medium being low in organic matter and does not retain available moisture that crucial for seed germination (Ball 1998). The treatments added to the lightweight aggregate medium did not improve germination, but may have aided in necessary moisture and mineral nutrients to the seedlings once they germinated based on the results. The control and green roof treatment had higher germination rates, regardless of base media or plant species. The notable exception was *Talinum,* that had 8% germination in the lightweight aggregate medium versus 25% germination in the greenhouse medium. The addition of the green roof treatment to greenhouse medium to plugs for green roof planting should be evaluated in a green roof study to determine long term benefits. However, this study indicated potential to improve media for germination of these green roof plant species.

Plant growth plants in the greenhouse medium were greater compared to those grown in the lightweight aggregate medium. The greenhouse medium control produced plants that grew among the largest plants in height, leaf count/plant width, and biomass for all plant species. The lightweight aggregate medium control was ranked the lowest for growth in all but one characteristic (*Talinum* biomass). The evaluated treatments yielded opposite results to the base media. The plants grown in the greenhouse medium improved with the fertilizer treatments, but decreased in growth when the other treatments were added. The plants grown in the lightweight aggregate medium increased with all treatments. The treatment that was most consistent with the base media was the green roof treatment. The green roof treatment significantly improved plant growth in lightweight aggregate medium, but reduced growth in the greenhouse medium. This reduction in plant growth was not necessarily an undesirable outcome. Plants that have reliable sources of available water, an organic matter content to support water retention and aeration allow for lush foliage growth. This may be detrimental on extensive green roofs, because the environmental conditions may not support lush plant growth (Nagase and Dunnett 2011). For growers that are selling plugs to be used on green roofs, the greenhouse medium allows for plants that are taller, wider, and have greater biomass. However, plant establishment is essential for growing plants on a green roof, and it could be improved by furthering research on media in plug propagation for green roof plants.

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